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FOUNDATION TREATMENT FOR EARTH DAMS ON ROCK

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FOUNDATION TREATMENT FOR EARTH DAMS ON ROCK

Thomas F. Thompson,*Affiliate, ASCE

INTRODUCTION

An increasing number of earth dam projects are being built on rock foundations. In many cases such construction requires new concepts as to proper foundation treatment, often taxing the ingenuity of the designer to contend with problems that are revealed either during the planning or investigational stages, or, since it is rarely possible to entirely visualize subsurface conditions before the foundation is opened up, as actual construction exposes unanticipated adverse geological features of the bedrock.(1)

Types of earth materials available within economical hauling distance from a proposed earth dam site sometimes offer but little choice to the designer. He must use the best material at hand, with full appreciation of its shortcomings, if any, and prepare a design that will afford an impervious, economical, stable barrier that is eminently capable of withstanding deleterious effects of seepage acting upon the base of the fill at the foundation and abutments. In contrast to concrete dam construction, some of the materials used in earth dams are susceptible to erosion under high velocity flows. Moreover, as experience has demonstrated, when piping of earth materials takes place, failure is progressive. Depending upon velocity of seepage and upon the density and cohesiveness of the material, it may be so rapid as to preclude the taking of remedial measures before the embankment is breached and the reservoir pool lost, with consequent hazard to life and property downstream and need for extensive repairs to the dam.(2) (Plates 1, 2, and 3)

The need for close cooperation between the engineering geologist and the soils engineer during the development of foundation design and in the solution of problems related to the foundations which are revealed during the progress of construction is obvious. This paper has as its purpose the outlining of general principles of foundation treatment as apply to earth dams on rock and the presentation of certain specific examples of procedures used recently by the Corps of Engineers in connection with dams constructed under its supervision in the western states. It is hoped that formal and informal discussions following the presentation will bring out procedures used by other agencies to contend with these, or similar problems.

Types of Rock Foundations

Variety in types of rock foundation for earth dams are at least as numerous as there are dam sites. Even though rocks of the same mineralogical composition and geologic mode of origin may be present at a number of sites, their history since emplacement is seldom, if ever, identical. Tectonic effects, chemical alteration and climate differences to which apparently otherwise

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similar rock formations may have been subjected can bring about profound dissimilarities in foundation properties from one location to another. These differences will necessitate different approaches to the problem of foundation preparation as well as variance in degrees of treatment required. Where a hard, generally smooth bare rock surface is present, and the subsurface investigations have conclusively proven the underlying formation to be water tight, it is obvious that little or no treatment is needed. Conversely, where the foundation rock is closely fractured or faulted, is loosely or openly jointed, is cavernous, variably altered or otherwise is of such character as will result in a highly irregular, rough surface along the base of the dam, detailed consideration must be given to the implications of these defects and best methods for their treatment developed.[3]

Foundation Preparation

General

Inasmuch as this paper is primarily concerned with treatment of the exposed foundation surface for earth dams on rock to give increased stability and to preclude the possibility of leakage damage to the structure, no discussion of embankment design is included, other than those features directly related to the problem.

Middlebrooks, [4] In a paper presented before the Centenial convention of the Society, and published in Civil Engineering, outlines the historical development of design concepts for earth dams, lists examples of unsatisfactory performance in the past that resulted in failures, and describes and illustrates up-to-date thought insofar as it applies to earth dam design and construction. Since benefits derived from impervious blankets or drainage blankets as well as drainage wells are treated in his paper, they are not repeated here. A comprehensive bibliography on the subject of earth dams accompanies Mr. Middlebrook's paper.

In general, the extent of stripping or excavation required to reach foundation grade for a dam is directly related to the depth and character of the overburden. Where weak soils are extensively present throughout the foundation and abutments, their presence must be compensated for by appropriate embankment design measures or they must be removed to the levels at which weathered or fresh rock of adequate strength and water tightness are reached. If strong rock is present at the surface or at a relatively shallow depth in the abutments, no stripping, or only the removal of material to below the depths of root penetration is commonly required. If clean, granular alluvial materials as represented by sands and gravels, occur to considerable depths across a valley floor, the bulk of the structure may be founded on them, with the use of a relatively narrow core trench, excavated to bedrock and backfilled with compacted impervious material, to provide a cutoff. In either case, a careful cleanup must be made to permit complete inspection and surface treatment, if necessary, of the foundation section upon which dependency for seepage cutoff is placed, thereby providing assurance that no open or loosely filled fissures, joints or bedding planes are present that might offer direct, high velocity seepage paths immediately under the impervious section of the dam. Where the bedrock is weathered or extensively fractured at foundation grade, the dam's impervious section is generally extended into the rock by means of a core trench to the depth at which improvement is noted. If pressure tests made in exploratory borings have indicated the need, an impervious grout curtain can be effected by pressure grouting through diamond drill holes so spaced along the bottom of the core trench as to provide the desired subsurface seal.

Shaping the Foundation

To the extent that it is economically feasible, good design and construction practice calls for shaping the rock surfaces upon which the impervious section of the dam will rest so as to minimize the effect of settlement differentials. If this feature is disregarded, cracking and shearing of the fill under the load of the completed embankment, may result. Where near-vertical or steep cliffs of appreciable height are to be enveloped in the impervious section, it is advisable to slope the faces of these declivities in such a manner as to distribute loading stresses along the base of the fill, where this is economically feasible. Overhangs of rock should not be permitted since these require the use of relatively expensive hand tamping procedures, and the degree of compaction attained is seldom as high as that forthcoming from use of normal procedures. Where overhangs are permitted, the resulting bridging of stresses resulting from compactive effort and the weight of the fill, if not the direct cause of cracking or shearing of the fill, may result in lower densities or actual voids in the portion of the dam protected by the overhang.

Use of Explosives

Blasting to remove rock above foundation grade or to shape the foundation should be carefully controlled in order to prevent the opening up of cracks or actual displacement of blocks of rock which otherwise would have provided a satisfactory bearing surface. As applies to the critical core trench section of an earth dam, the degree of control exercised should be fully as close if not closer than is employed in arriving at the foundation for a concrete hydraulic structure of comparable height. In this respect, the specifications should carefully define type and quantity of explosives permitted, minimum lateral distance from completed portions of the foundation that blasting is to be allowed and permissible proximity to foundation grade for drill hole blasts. On some projects, no blasting whatsoever is allowed within 100 feet of a completed foundation surface, and the depth of drill holes for blasting is limited to two-thirds of the remaining depth of excavation, with the final few feet of rock being required to be taken out by barring and wedging. Whatever the means used by the designer for control of blasting, his objective should be to provide as clean, unfractured a foundation surface as possible with a minimum amount of disturbance to the rock underlying. Careful blasting is particularly necessary where foundation preparation is being advanced concurrent with subsurface grouting in nearby sections of the foundation since the possibility of harmful effects from blast created shock waves on a completed grout curtain are too obvious to merit discussions.

Foundation Pressure Grouting(5)

General

Foundation pressure grouting beneath an earth dam is primarily for the purpose of providing a tie between the core material of the dam and the tighter rock normally found at depth beneath the foundation and abutments. The need for a grout curtain is directly related first, to the value of the water retained by the curtain which otherwise might be lost through subsurface leakage, and second, to considerations related to the possible damaging effects to the structure if appreciable seepage is permitted to occur. At some sites where springs issue from the prepared foundation surface, curtain grouting or area grouting may be necessary as a means of drying up the foundation so that initial lifts of earth fill can be compacted at the most effective water content for securing required densities. The need for and extent of grouting is

normally determined as the subsurface explorations of the site are advanced, using water under pressure applied through packers expanded at various levels in borings to establish the locations of leaky horizons. Pressure tests may be supplemented by pumping tests, combined with observations on draw-down in adjacent holes, by means of which the coefficient of permeability can be established.

Having determined the leakage propensities of the foundation rock and need for a grouting program, the designer should select the grouting medium and and procedure that will provide an effective and economical cutoff. The most extensively used grouting material is a slurry composed of neat cement and water. However, adulterants of various types are commonly employed. Under certain conditions (generally where large openings must be filled or where channels contain running water are present), sanded cement grout mixtures are used with admixtures to increase the suspension and penetration properties of the mix. Other grouting media are natural clay or silt slurries, bentonite slurries, molten asphalt and chemicals that have the property of hardening upon introduction of controlled amounts of other chemicals or gases.

Since the subject of foundation grouting has too many ramifications to permit a comprehensive discussion within the necessarily limited scope of the present paper, only the techniques most commonly used on western earth dams, to the knowledge of the writer, which invole the use of a mixed cement and water grout and its introduction under pressure through holes drilled either from the foundation of the impervious cutoff, or from the crest of the completed embankment, will be discussed.

Based on evaluation of the economics of water storage and embankment design plus the geological interpretation of the results of core borings and pressure tests which serve to indicate the degree of openness and extent of inter-connection of water passageways through the foundation, the engineer selects a tentative depth and spacing for the grout holes that will result in the desired curtain and prepares as accurate an estimate as is possible of the probable grout "take". This is used in the overall study of feasibility of the project and for the preparation of contract specifications. The specifications must be written so as to provide flexibility in decreasing or increasing the grouting program since it is rarely possible to estimate with a high degree of accuracy the effects of concealed geologic factors that will largely influence the ultimate extent of drilling and grouting required. Other features related to the grouting specifications are the proper angle of drill holes for intersecting the greatest number of groutable seams, the extent of pressure washing of joints and fissures that may be required, the establishing of ultimate depth of the grout curtain and a breakdown of this depth by zones, pressures that can be safely used, range of water-cement ratios desired for the work, equipment to be employed and methods that must be used for grout injection.

The question as to the best time during construction for grouting the foundation - before, or after construction of the embankment - is highly controversial, with strong proponents for each side.

Those who advocate foundation grouting from the level of the foundation surface point out the hazards related to possible heaving of the fill and further indicate in support of their stand that the degree of effectiveness of any grouting program is a function of the extent that erodible, fracture filling materials are removed by washing of the seams under pressure. When the core is composed of materials that have little resistance to erosion, as is the case where fill materials of low degree of cohesion are employed, the wash water may attack the base of the fill where it contacts the seams and actually transport

this material into the filter zones or more pervious sections of the dam. Later, when grouting is attempted, it is contended that the path taken by the fluid grout will be that of least resistance, along the pipes created by washing, and that the end result will be a less effective and more expensive curtain in this critical contact section of the dam, and furthermore, that grout lost into the filter zone may decrease actual effectiveness of the filter. They conclude that the best time to treat defects of the foundation is when the rock is exposed and that if grouting is performed at the time, the danger of damage to the fill from uplift due to grout pressures is eliminated, direction of travel of the grout can be better determined, and, from the standpoint of economy, that the amount of grout required will be kept to a minimum.

Those who take the opposite stand, that foundation grouting should be performed after the fill is completed, hold that by grouting after construction, imperfections of the bedrock at or close to the foundation contact may be better remedied by the pressurized grout rising under the confinement represented by the weight and lateral extent of the fill, and further, that cracks or shear planes in the fill itself that developed during the period of construction will be entered and sealed by grout, thereby rendering the dam more impervious and secure against the possibility of piping when the reservoir pool is raised.

From an unbiased viewpoint, it appears that both methods of grouting have their proper place and should merit consideration at any given site, with advantages and disadvantages of each carefully weighed to determine their respective adaptabilities or shortcomings. Where the character of the material used in the core section is not susceptible to erosion under pressure washing but may be sheared or cracked by the compaction procedures, and particularly where the shape of the foundation is highly irregular and therefore conducive to differential settlement, grouting from the surface of the structure after it is completed may justify the added expense. Where these conditions do not exist, the more generally followed practice of grouting from the rock surface seems preferable. (Plate IV).

Methods of Injecting Grout

The present discussion is limited to the two most commonly used methods for injecting cement grout; i.e. by stage grouting and by stop grouting. Under both methods, the "split spacing" procedure of drilling and grouting is commonly followed; that is, a primary set of holes is drilled and grouted at a predetermined maximum spacing, generally no more than 20 feet, and succeeding sets of holes are spaced so as to split the intervals between previously completed sets; this process being continued until the spacing is such that no appreciable amount of grout can be injected at the established maximum pressure.

Stage Grouting

In effecting a grout curtain by this method, which is extensively used by the Corps of Engineers, holes are drilled on the maximum spacing to a full depth zone of the curtain, or until conditions revealed by drilling such as water loss or gain indicate an intermediate stage to be necessary. Each hole is then cleaned out, pressure washed, pressure tested, and grouted at a pressure selected after consideration of the strength of rock, and the depth at which pressure is being applied, with appreciation of uplift possibilities. When the grout begins to take its initial set in the hole it is removed by washing, chopping or by use of a "fish tail" bit. This completes the stage for the hole. After an appropriate interval to permit the grout in the seams to strengthen,

the hole is deepened by another stage, and the entire procedure is repeated as many times as is necessary thereafter until the final depth of the zone to be grouted is reached. In completing the last stage of any hole, the cleaning of grout from the hole is omitted. In multiple zone curtain treatment of the foundation, the grouting of successively lower zones permits the use of higher and higher pressures and, as a result, the spacing of holes in the lowest zone may be much wider than that necessary in the uppermost zone, where lower pressures must be used.

The advantages of the stage grouting procedure largely lie in its flexibility for meeting all conditions of openness that may be found within a given stage, although this benefit is not fully realized unless accurate interpretations are derived from the subsurface information made available by drilling and pressure testing. The washing, pressure washing and pressure testing are accomplished from the top of the hole for all stages and the use of an expansion plug, with its attendant difficulties, is not required. Perhaps the most important advantage of the stage grouting method is that as the hole is deepened and greater pressures are applied, the entire hole is subjected to these increasing pressures. The principle disadvantage of stage grouting is the need for cleaning out the hole after each stage, with attendant loss of time and grout waste.

Stop Grouting

Under the stop grouting method, each grout hole is drilled to its final depth and grouted by zones through a stop or packer which can be moved and set at successively shallower depths upward from the bottom of the hole. Grout pressures are generally reduced with each succeeding setting of the stop. For multiple zone treatment, the lowest zone is grouted, using the split spacing method, and then the shallower zones are similarly treated until the curtain is completed up to the foundation level.

This method of grouting has most of the advantages of stage grouting. Imperfections disclosed during drilling may receive separate treatment in much the same manner as for stage grouting, using the expansion plug to isolate desired portions of the hole. Any imperfection so disclosed may be grouted at the mix and pressure best adapted for correcting it, and if a double expansion plug is used, pressure washing and pressure testing can be concentrated within a limited interval of the hole, thereby improving efficiency of these operations. This method also eliminates the necessity for cleaning out holes previously grouted, as required in stage grouting. Disadvantages of this method of grouting are related to the fact that the grout may bypass the stop through vertical or inclined fractures which intersect the hole above, with resulting uncertainty as to which portion of the hole is actually being treated, and the stop grouting method does not allow use of maximum pressures in the upper part of the hole, as is the case with stage grouting. Since grout is first applied to the lower reaches of the hole, there may be a tendency towards wastage of grout which can escape through unsealed fractures of a zone or zones overlying.

Combined Method

Recent difficulties encountered in grouting seamy or blocky granite foundations at Folsom and Isabella dams, now being constructed in California under jurisdiction of the Sacramento District of the Corps of Engineers, led to the utilization in the same holes of certain features of both grouting methods. The seams and joint filling materials in the weathered zone of the rock could not be cleaned by pressure washing to the extent that they would provide a

good grout bond. In using the stage method of grouting with increasingly higher pressures for successive depth zones, it was found that the grout would break back through upper previously sealed seams, and as a result, there was no assurance that the lower zones were being subjected to the pressures required for the penetration of finer cracks. This difficulty was overcome by grouting to the depth of the first zone by conventional stage grouting methods, cleaning out the grout in the hole, drilling the first stage of the second zone, and then grouting this stage with an expandable packer until refusal was obtained. As soon as a condition of little or no grout take was reached through the packer, the packer was removed from the hole and a grouting connection made to the grout nipple set at the surface of the core trench. By repeating this procedure at each successive depth stage, it was possible to overcome the problem of surface leakage, derive the full benefit of stage grouting insofar as applying the maximum pressure used at any depth to the entire section of the hole, and to attain as effective a grout curtain as possible in this type of material to the depths required.

Foundation Cleanup

Cleanup of the impervious section foundation, when grouting is conducted from the foundation level, is normally delayed until after the completion of grouting, at which time all disturbed rock, and spilled or washed grout which might conceal surface imperfections and pockets of alluvial material, are removed. If grouting is to be performed from the crest of the dam, the foundation is thoroughly cleaned, washed, subjected to whatever dental or other type of superficial treatment is needed, given final inspection, and the first critical lifts of fill placed.

In either case, an equally painstaking and thorough job must be performed. The effects of mechanical excavation and blasting performed to reach rough grade is often reflected by loosening of blocks of rock. These must be removed by hand picking or barring and wedging and either wasted or used elsewhere in the fill. Vertical faces or overhangs are sloped back to the extent possible without the use of explosives. Pockets of sand and gravel are removed by use of hand shovels and soft, erodible seams resulting from localized decomposition of the rock or faulting are cleaned out preparatory to final washing and dental treatment.

Washing

Pressure washing of the foundation surface is done to assure as clean a surface as can be obtained and to remove fines that may have worked into the seams, and if not removed, could prevent their complete filling during subsequent measures taken to prevent seepage. This washing also serves to test the degree of fixation of rock projections which might otherwise be worked loose by hand tamping or rolling during compaction of the first lifts of fill. The washing is conducted by directing the wash-stream from a hose in such manner as to clean from higher portions of the foundation toward lower areas, where the debris is loaded into skips or wheel-barrows for transportation to disposal areas. Water which accumulates in depressions is removed by small air pumps, hand bailing or the use of an aspirator to reach narrow water filled fissures. On some jobs where the rock is fresh but contains deep open joints defining large blocks of firmly fixed rock, the use of an air-water jet for final cleanup has proven effective. This method was used with success for a portion of the earth dam foundation surface at McNary Dam in Washington. (Plate V) Where the nature of the rock is such as to be softened by washing with water,

blow pipes and compressed air have proven effective. If the foundation is closely jointed, blocky rock, caution must be used to avoid removal of satisfactory foundation material by over-zealous pressure washing.

Treatment of Foundation Surfaces

Corrective measures to be applied to the immediate surface of the cleaned rock foundation upon which dependency for a cut-off is placed are such as will minimize the difficulties in securing compaction in deep local depressions that result from removal of blocks of rock or excavation of soft areas, and will offer the maximum protection against seepage acting on the base of the fill. One or more of the following described measures, some of which are new while other have been long employed, have been used recently for earth dams being built in the west by the Corps of Engineers.

Dental Treatment

If final foundation cleanup results in a surface that is marked by sharply reentrant pockets due to plucking out of joint defined blocks, or "potholing" by erosion in a river channel, it is often most expedient to fill these holes with concrete. This is particularly true when a concrete plant is in operation on the project, the price of concrete is favorable, and facilities are such as will permit its easy transportation to the foundation requiring treatment. If 1-1/2-inch or smaller maximum sized aggregate concrete is readily available, this type is preferred for use in dental treatment, since its use will permit a more effective placing in small openings with less tendency for segregation than is the case of larger aggregate concrete. The wet concrete is thoroughly rodded into the voids and its upper surface brought up to the general level of the surrounding rock. The dental concrete serves a dual purpose - first, it smoothes up the foundation to the extent that subsequent compaction difficulties are decreased, and second, it provides a non-erodible impervious seal as a measure of protection against water which may migrate through joints at the base of the feature treated after the reservoir is in operation.

Hand Tamping

Under similar conditions of foundation to those covered under dental treatment, and where the fill material employed is of a type offering high erosion resistance, or, where no open cracks are present at the immediate bottom of the holes, compacted earth is commonly used for filling the depressions. Hand tampers, either air or gasoline motivated, are employed to tightly ram the soil into place and obtain the degree of compaction specified for the overlying fill.

Slush Grouting

Where fresh but highly fractured or jointed rock is disclosed at grade for the impervious core of earth dams, the Corps of Engineers in recent years has adopted a policy of requiring application of a sealing treatment of one type or another to the defects in the surface upon which the impervious core material will rest. This is to provide protection against possible damage from seepage erosion at the base of the fill. The application that has been most widely used - at McNary, Lucky Peak, Isabella, Folsom and Mormon Island Dams - is one involving the use of a sand-cement slurry. The process of applying the slurry is referred to locally as "broom" or "slush" grouting. The slurry, with sand cement ratio ranging from 3:1 to 6:1, is mixed either in a small mobile concrete mixer or in a conventional grout mixer, which is located close to the area being treated. The slurry is generally carried by

hand in buckets to the places of application, there to be distributed along the trend of the foundation imperfections. The slurry is worked into the fractures using a stiff broom, with care devoted to preventing accumulation of grout on unfractured fresh rock surfaces or areas of weathered rock where it would not be needed in any event, and conceivably might be harmful. The water-solids ratio of the slurry is varied to meed conditions present. If the rock is closely fractured, with fine cracks, the water content is increased and the finest sand or other inert filler available is used to permit the ready entry of the slurry into minute seams. Where wide cracks are present and extend to depth, a stiffer slurry with coarser sand is employed to reduce the extent of shrinkage cracking. At McNary Dam, in the Walla Walla District, joint conditions in the massive basalt in the portion of the foundation where this type of corrective measure was employed were such that they could be effectively plastered at the surface with a stiff, sand cement mixture, as shown on Plate VI. At Lucky Peak Dam where half the foundation area is basalt in which nearly vertical, hexagonal, columnar jointing is exceptionally well developed, (Plate VII), erosion by bedload of the Boise River had planed off the tops of the columns and opened up surrounding joints by scouring out the alteration filling. The altered material in the joints at this location normally renders the rock relatively tight. To correct this defect, as shown on Plate VIII, a comparatively fluid slurry was broomed into the joints to seal them to depths at which the natural filling was undisturbed - in most cases, 3 or 4 inches below the tops of the truncated columns.

The cutoff trenches for the earth wing dams at Folsom Dam, for the most part, are bottomed in firm decomposed granite in which only occasional ribs of fresh rock were encountered. The joints in the weathered rock along the floor of the cutoff were tightly sealed because of the natural expansion of this type of material in the process of decomposition, that no surface sealing was required. At the relatively few locations where hard rock was encountered, a sand-cement slurry of appropriate consistency was applied to open fractures and joints.

Mormon Island Dam, where the foundation for the core trench is a closely jointed and foliated, metamorphosed volcanic rock (amphibolite) offered a difficult problem in slush grout treatment. Here the washing necessary for cleanup resulted in an extremely ragged surface, with thin plates and "shark fin" projections oriented parallel to the major joint pattern which was at an acute angle to the axis of the dam. Although a thin, fluid, sand-cement slurry was used to penetrate the comparatively tight cracks evident in most of the foundation, in some locations, where there was a possibility of breaking down the projections by action of rollers during compaction of first fill lifts, the slurry was thickened and the depth of its application increased so as to give structural support to the thin projections.

At Isabella Dam, conditions encountered in the weathered granite foundation for the core trench were similar to those at Folsom, and the application of a slurry seal was restricted to open fractures in hard, fresh rock ribs, the majority of which were disclosed in the steep slope of the left abutment.

Use of Gunite

At Isabella Dam, the presence of a heap of large weathering - isolated residual granite boulders and unanticipated very open jointing in the underlying bedrock along a portion of the core trench in the left abutment required special treatment. (Plate IX) Some apprehension was felt that the raising and lowering of the reservoir pool incidental to its operation for flood control might set up a piping action on the relatively thin section of compacted

decomposed granite which formed the cutoff; and some means of sealing the cracks as would obviate this worry was sought. After carefully evaluating the various measures that might be taken, relative costs and probable effectiveness, it was decided to apply a coating of gunite to the pressure washed, clean rock surface. This decision was influenced by the fact that gunite was required for other parts of the construction which would necessitate the mobilization of guniting equipment and personnel in any event, plus the belief that by use of gunite, with several coats of application, it would be possible to fill out the trench walls below overhangs, thereby facilitating compaction of fill and to strengthen the core wall by bonding together joint defined blocks which might otherwise be displaced by the heavy rollers during early stages of embankment construction. A coating of gunite that averaged an inch in thickness was applied and the results obtained were all that could be hoped for. Plate X shows the gunite coating in place for a portion of the core trench and illustrates the effective seal obtain across the formerly openly jointed core trench wall.

Asphalt Membrane(6)(7)

A unique, and under favorable conditions, effective method of creating a seal to protect core materials against damage from seepage that may develop along cracks which immediately underlie the core was employed recently for part of the jointed, open basalt foundation at McNary Dam. (Plate XI) This method involves the application under pressure by hand sprays of so-called "catalytically-blown asphalt," applied over the carefully cleaned, washed foundation surfaces at temperatures in the range of 300 degrees to 400 degrees fahrenheit. (Plate XII). By using two applications, it was possible to build up a coating over the irregular rock surface which averaged 3/8-inch in thickness. At normal air temperatures, when the membrane had cooled, the film created was a tough, slightly elastic coating. (Plate XIII). The only difficulties encountered in application were where exceptionally wide joints (over 1/2-inch) were present in vertical or near vertical faces and the asphalt did not bridge the joints. Where this condition was encountered, the wider joints were first filled with asphalt that had cooled sufficiently to become quite viscous, and then coated across with the spray method of application. The following table gives specification for the asphalt used:

Table 1

Materials Specification for Catalytically - Blown Asphalt

Penetration Grade	50 - 60
Flash Point, not less than	425° F.
Softening Point	175° - 200° F
Penetration at 77° F, 100 grams, 5 secs	50 - 60
Penetration at 32° F, 200 grams, 60 secs, not less than	30
Penetration at 115° F, 50 grams, 5 secs, not more than	120
Ductability at 77° F, 5 cm. per min, not less than	3.5 cm.
Loss at 352° F, 5 hours, not more than	1.0%
Penetration of residue at 77° F, 100 grams, 5 seconds, as compared to penetration before heating, not less than	60 %
Bitumen (Soluble in carbon tetrachloride), not less than	97 %

Greatest difficulties in placing the membrane were related to the presence in the foundation of small springs which tended to float off the film as it was applied, and failed the membrane locally. Corrective measures taken, where this was the case, are described subsequently.

In evaluating the results obtained, properly classified so far as experimental, it should first be pointed out that the cost is quite high, for the relatively small area where it was used averaging $3.40 per square yard, and the work must be done by hand. The hand spray attachment used proved quite satisfactory since it enabled the operator to work small or large areas as necessary and still give the degree of special attention necessary to correct particularly bad spots. Wide joints on near-vertical walls cannot be effectively covered by spraying alone and these must be plugged by hand before spraying. Greatest success in use of the material depends on the presence of a firm rock surface free from seepage at the time of application. Although care was required in placing and compacting initial lifts of fill upon the prepared membrane surface, the elastic properties of the film eliminated most of the normal hazards resulting from compaction across an irregular rock surface.

Unwatering the Cutoff Foundation

General

On some jobs, where the base of the core trench is below the water table, in spite of use of closely spaced grout holes for both area and curtain grouting, it has been found to be impossible to dry up the foundation for the cutoff to the extent that the first lifts of impervious fill could be placed and rolled at the desired moisture conetnt. Where seepages rise through rock fractures, the effect of dumping impervious fill on the foundation is to create a mud, impossible of compaction, with piping out of fill taking place concurrent with its placement. Rising water, as previously mentioned, was the prime cause of difficulty in the construction of the asphalt diaphragm employed for a portion of the core trench at McNary Dam, and presented a problem in securing proper compaction at the base of the cutoff at Lucky Peak, Mormon Island and Folsom Dams. To contend with this problem, and directly dependent upon the degree of localization of points of water issuing from the rock, one or the other of the following expedients was resorted to at the jobs cited.

Confinement in Standpipes,

Where the rising water is under low head and has a definite point of issue within a relatively small area, a standpipe was successfully employed. Depending upon size of the seepage area to be contained, a corrugated iron pipe of appropriate diameter is placed over the spring area, dry packed around its peripheral contact at the foundation with quick setting (lumnite) cement, and earth is hand tamped around the outside of the base of the pipe, while the water inside is kept pumped down, until an impervious seal is obatined. The fill is then brought up, adding increments of standpipe as required, until it reaches a height greater than the head of water within the pipe. When this condition is attained, the pipe is filled with rodded concrete, grout or heavy clay and the construction of the fill continued upwards and across the top of the plugged pipe by conventional methods. The most obvious disadvantages of this procedure are the need for hand tamping in proximity to the standpipe as the fill is raised and difficulties related to securing a watertight seal at the base of the standpipe.

Grouted French Drains

At Mormon Island, Folsom and McNary dams, the problem of drying up larger areas in the foundation for the core trench so as to permit placing of first fill lifts was solved by cutting drainage trenches through the areas of concern sloped so as to drain the water to pump sumps located outside the foundation for the core, and which were kept pumped down. The ends of the drainage trenches adjacent to the sumps were blocked by means of concrete plugs, near the base of which two pipes were placed - one continuing beyond the plug to the extreme end of the drainage trench while the other terminated a short distance inside the plugged drain and served to pass seepage water through the plug. The trenches were backfilled with pervious gravels (Plate XIV) to permit ready drainage, and the surface of the gravels protected from later infiltration of fill materials either by means of a layer of heavy brown paper and burlap or by an appropriate thickness of stiff concrete. The fill was then raised to a height as would overcome the hydraulic head of the foundation water, the two pipes extended upward by use of an elbow outside of the concrete plug, and the gravel drains tightly grouted by introducing cement grout under low pressures through the pipe extending to the extreme end of the trench, with the drain pipe serving as a vent to permit escape of water and air from the gravels. When only grout issued from the vent, a valve on the end of this pipe was closed and a slight positive pressure maintained on the system until the grout had set. Following grouting of the drains, normal fill construction was commenced. If the shape of the wet area so dictated, an arcuate, or longitudinal trench parallel to the trend of the core was dug, with laterals leading to the side of the core area and the grout introduced through a bulkhead at one end and its return checked through the drain pipe extended upwards from another bulkhead at the opposite, lower end of the trench.

Compaction of First Layers of Fill

Having applied all surface and subsurface corrective measures to the foundation that are needed, there still remains the problem of how best to bond the embankment to the prepared rock surface. In recent years, the Corps of Engineers has developed specifications for the use of heavy, rubber-tired compaction equipment. As compared to the requirements for sheepsfoot-type compactors, somewhat greater density is obtained, thicker lifts can be employed, and the number of roller passes appreciable decreased, resulting generally in lower cost. Disregarding the relative merits of both types for compacting fills above immediate foundation levels, a discussion of which is beyond the intent of this paper, the fact remains that there are certain advantages forthcoming from use of the rubber-tired roller at foundation levels. These advantages are related to the fact that thicker lifts of fill can be compacted than is the case with the sheepsfoot roller, and the danger of loosening projecting blocks of rock by the prying action of the roller teeth is eliminated. When the first lifts of fill are thin, as is required for compaction by sheepsfoot rollers, the possibility of rupture of an impervious membrane or cracking of a slush-grouted surface is obvious. By placing the fill material slightly on the "wet" side of its optimum moisture content and using pneumatic rollers after the rock surface is sufficiently leveled (either by dental treatment or hand tamped earth) to permit conventional spreading and compaction, a more effective contact around the unavoidable irregularities of the rock surface can be attained.

CONCLUSION

The use of earth dams for flood control, reclamation or water supply is on the increase because dam sites susceptible to other types of construction have largely been exploited. Moreover, earth construction offers greatest flexibility in adaption of design to topographic, foundation and economic factors. Many earth dams recently completed, in the process of being built or in planning and design stages involve construction in part or completely on a rock foundation. Where this condition is present, it is of utmost importance that full consideration be given to seepage effects under or along the immediate foundation surface. Treatment of foundation defects must be such as will insure against damage to the foundation or fill and will preclude excessive water loss during operation of the reservoir. Measures that may be taken are numerous. The designer's responsibility is to select the most appropriate methods of foundation protection and the field engineering and inspection staff should give careful attention to their application towards attainment of the ultimate goal - a safe, stable, seepage-resistant structure.

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Plate I - Failure of small earth water supply dam located in the foothills of the central Sierra Nevadas. In large part attributable to inadequate foundation treatment.

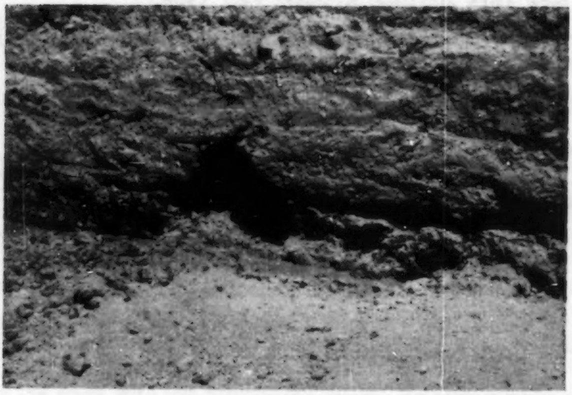

Plate II - Open fissure immediately adjacent to point of failure at base of fill.

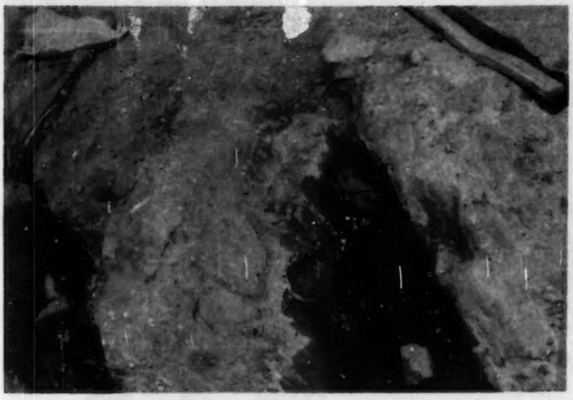

Plate III - Water Rising in Spring from Bedrock at Failure Point.

Plate IV - Grouting Operations Underway from Floor of Core Trench at Isabella Dam.

Plate V - Pressure Washing Foundation for Washington Shore Embankment, McNary Dam.

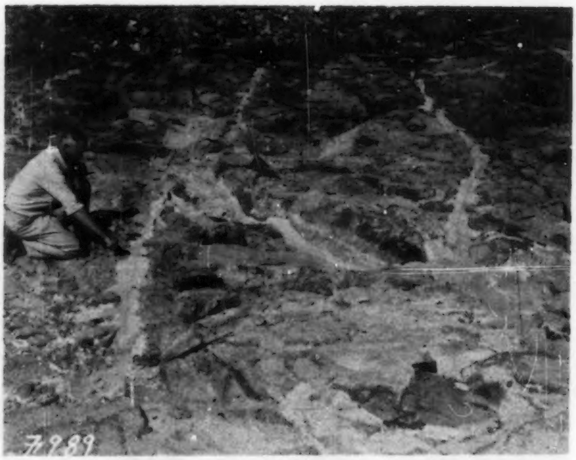

Plate VI - Plastered Sand-Cement Covering of Slurry-filled Joints, Foundation for Washington Shore Embankment, McNary Dam.

Plate VII - Truncated Columns of Basalt - River Section Foundation, Lucky Peak Dam.

Plate VIII - Sand-cement Grout Slurry being Applied to Eroded Joints at Foundation Surface for Lucky Peak Dam.

Plate IX - Slurry Treated Rock Surface.

Plate X - Open Fractures in Granite Bedrock on Wall of Cutoff Trench, Isabella Dam, Kern River.

Plate XI - Same Area as Preceding Showing Appearance after Application of Guhite.

Plate XII - Ragged Rock Surface Prior to Application of Asphaltic Membrane, McNary Dam.

Plate XIII - Method of Application of "Catalytically Blown Asphalt" Membrane, McNary Dam.

Plate XIV - Appearance of Completed Asphaltic Membrane, McNary Dam.

Plate XV - French Drains for Unwatering Wet Spots at Base of Core Trench, Mormon Island Dam.